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High-Performance Computing Applications in Wind Energy

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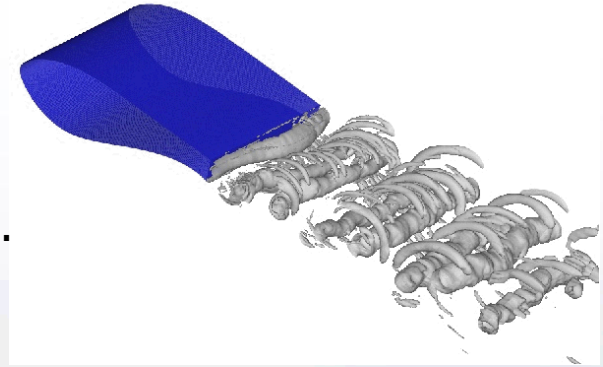


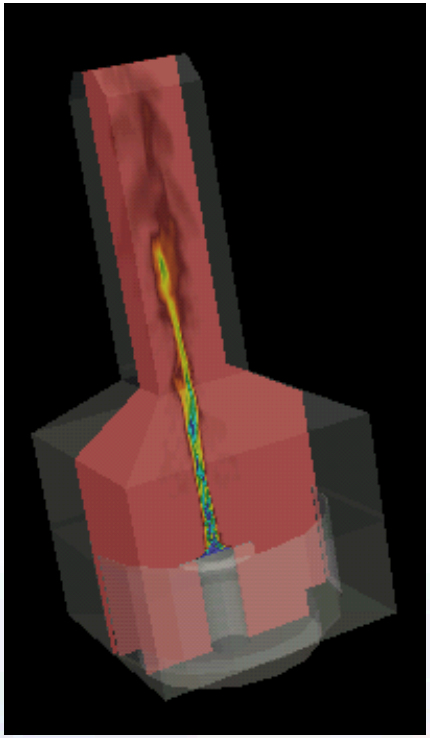
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Topics Covered

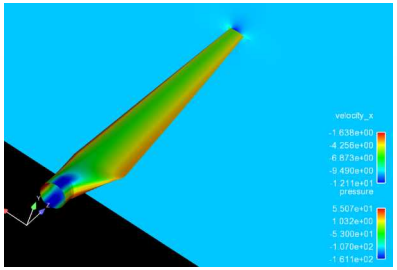
- **Simulation Software Development**
  - *Scalable* CFD codes for turbulent flow
  - Code features enabling wind energy simulations

- **Applications of HPC in Wind Energy**
  - High-fidelity CFD models
  - Probabilistic Modeling

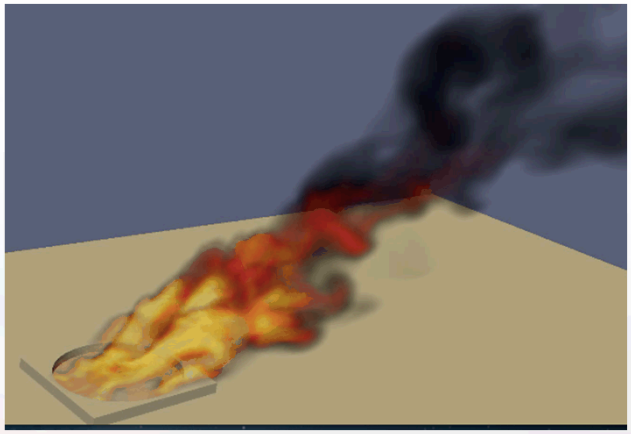
Unstructured Grid Large Eddy Simulation Capability for Turbulent Flow



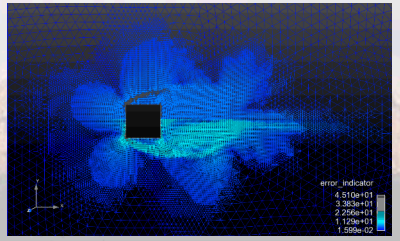
FLAME Facility



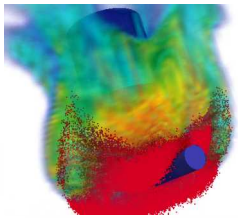
3D wind blade



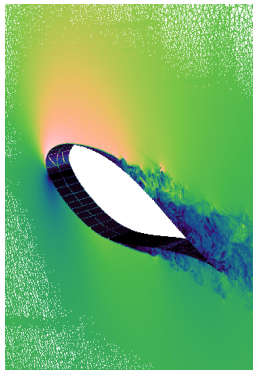
XTF Facility



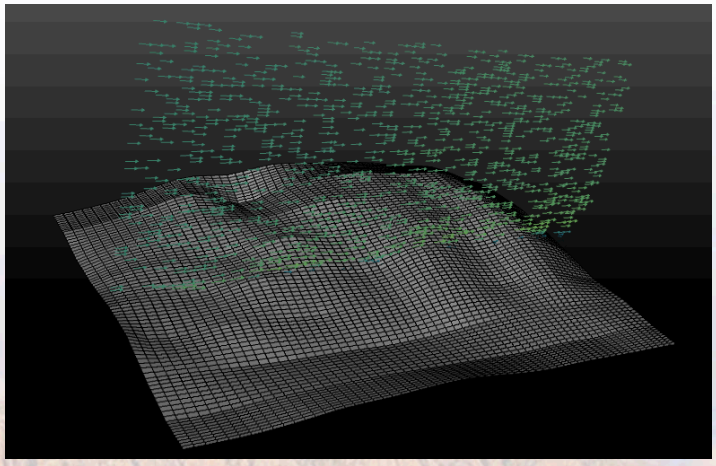
H-Adaptivity



Propellant burn



VAWT airfoil



1.6 km section of Angel Fire, NM

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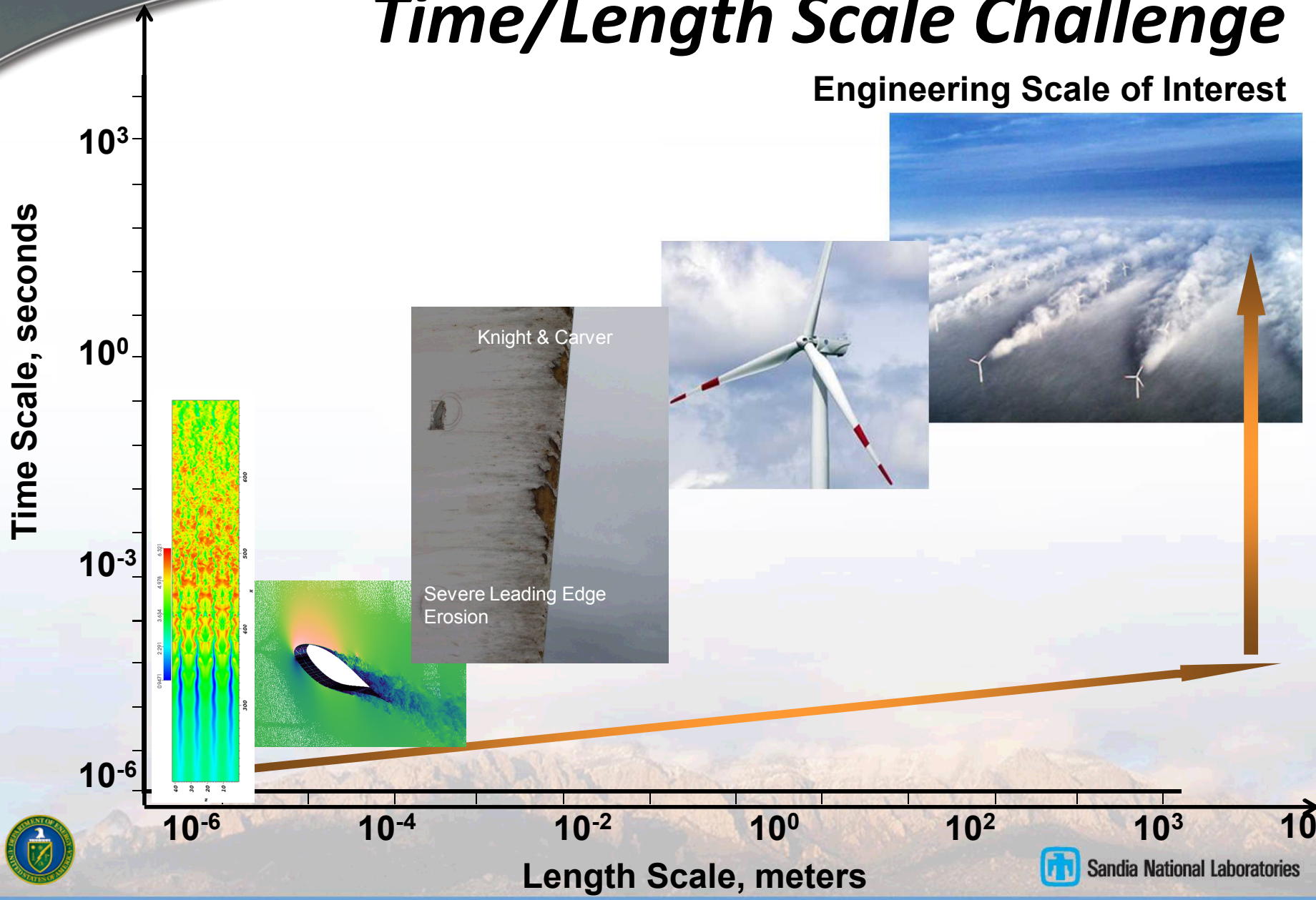
Time/Length Scale Challenge



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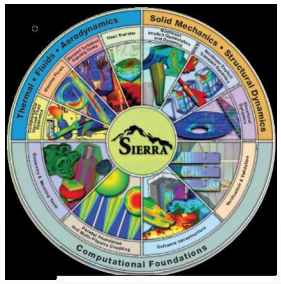
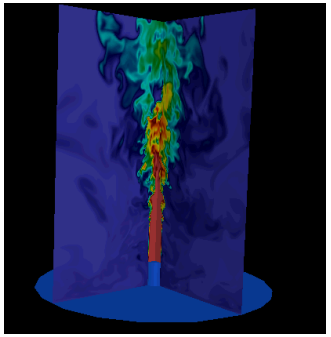
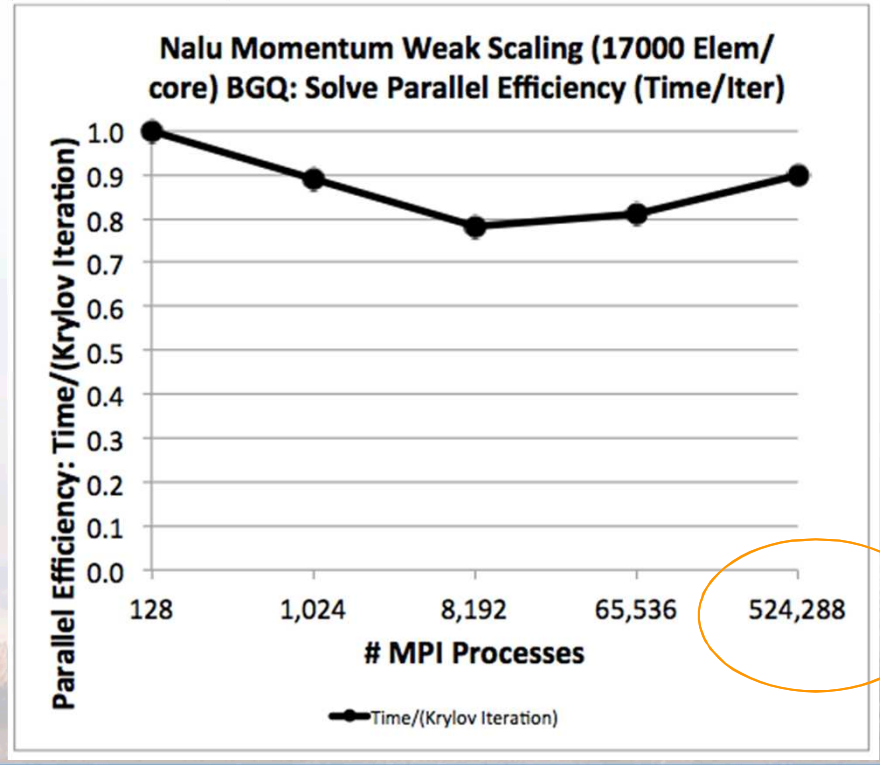
Today's Extreme Analysis Demonstrates Optimal Scaling O(10 billion) elements)



Trilinos

Nalu
low Mach





Fully implicit momentum solve (GMRES/SGS)

Core Algorithm:
generalized unstructured approximate projection method

~20million:10 billion elements unstructured hex mesh

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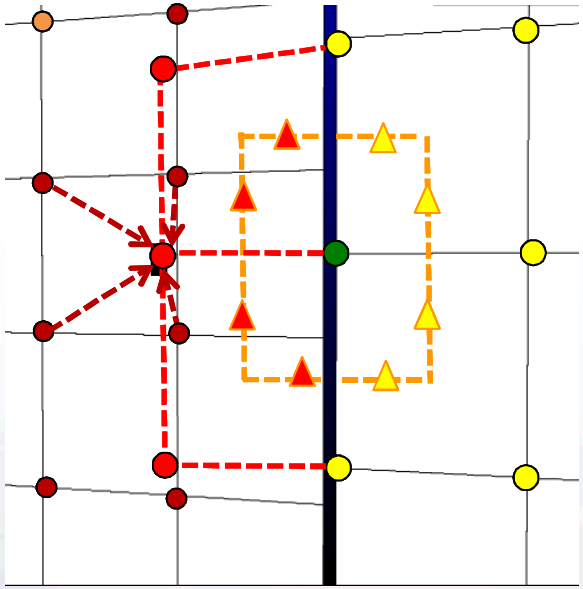
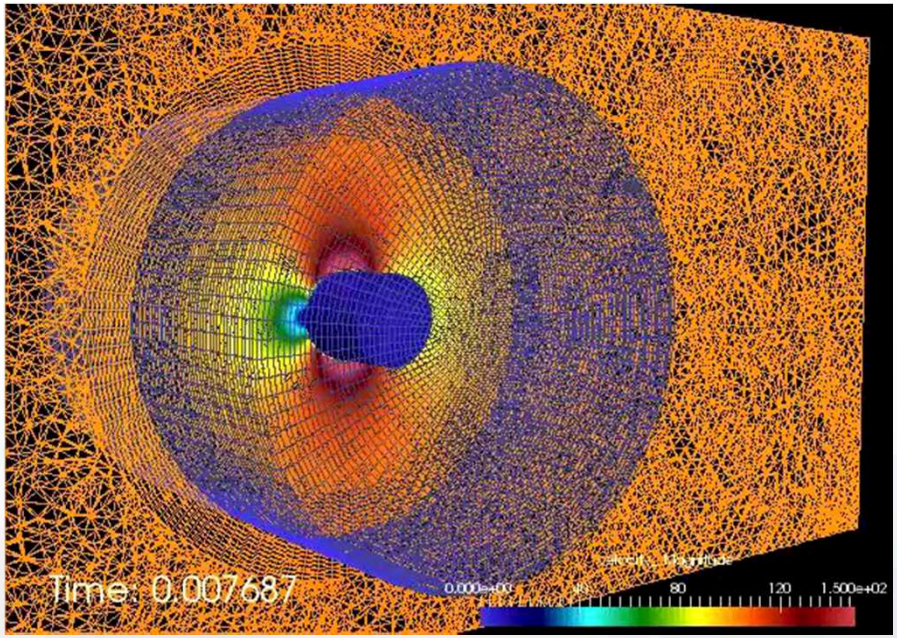
Topology Changes Add Complexity (sliding mesh)

- CVFEM/DG and Halo-Cell Approaches have been researched and developed (Domino, 2008, 2012, 2014)

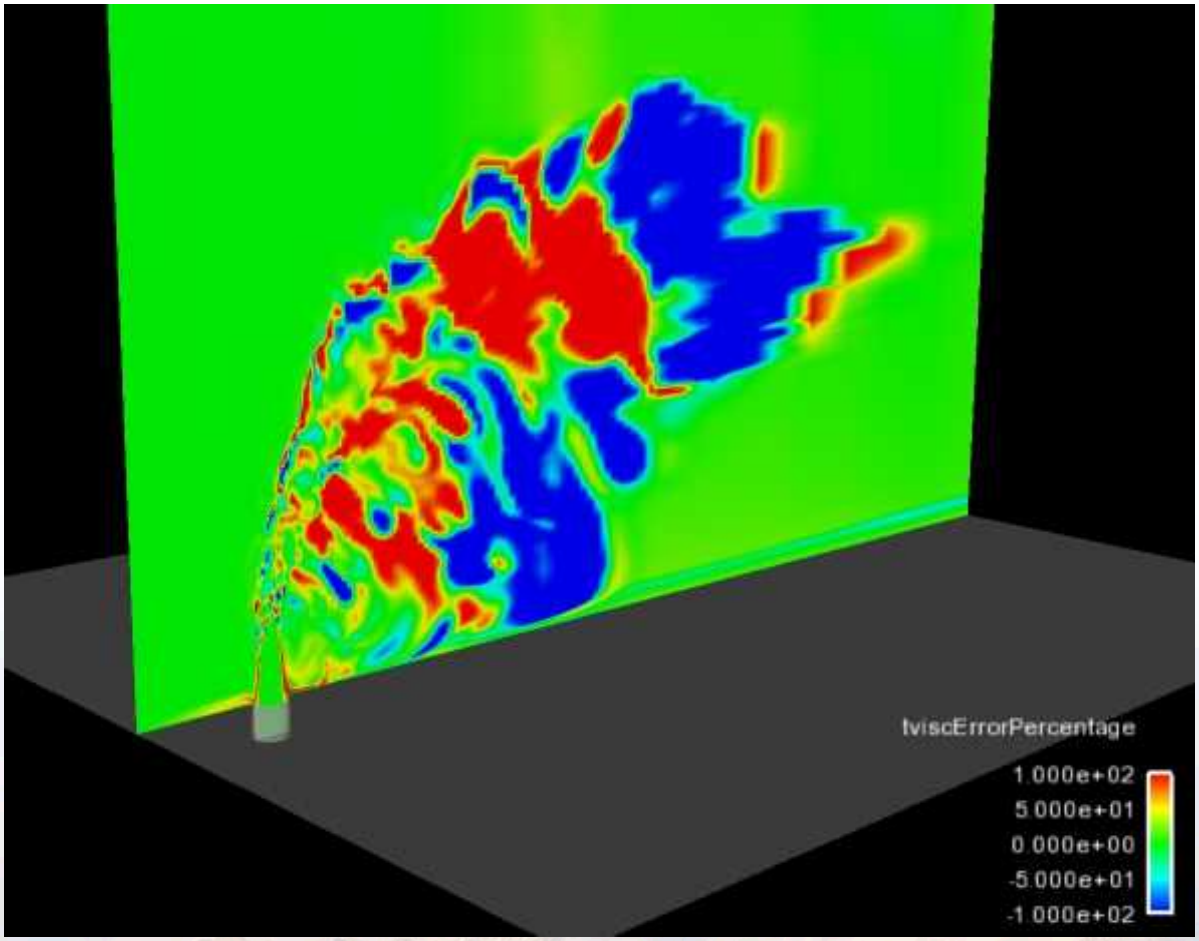


Extension of Halo (Stejil, 2008) and extrusion (Blades, 2006) procedure(s) to low Mach (Domino, 2013)



Re~1000 flow past 45 RPM cylinder

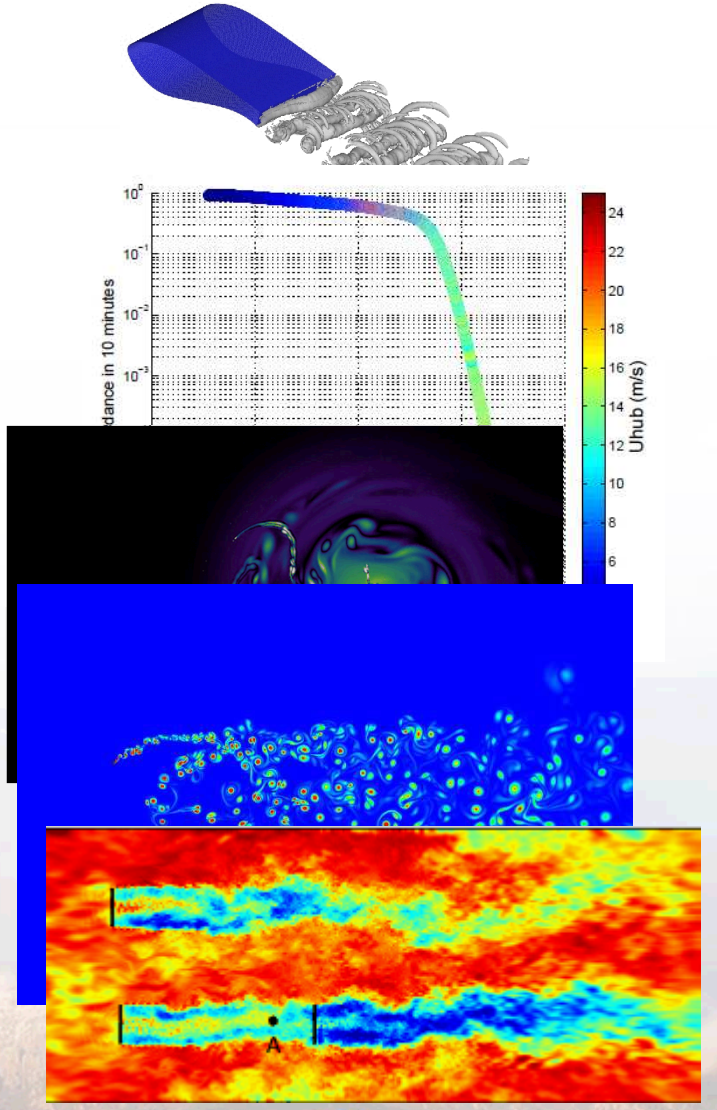
Topology Changes Adds Complexity (mesh adaptivity)



Re 5,000 variable density jet-in-Xflow;
Image is Error Transport Equation for LES

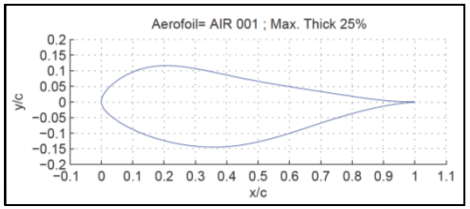
Wind Energy & HPC @ Sandia

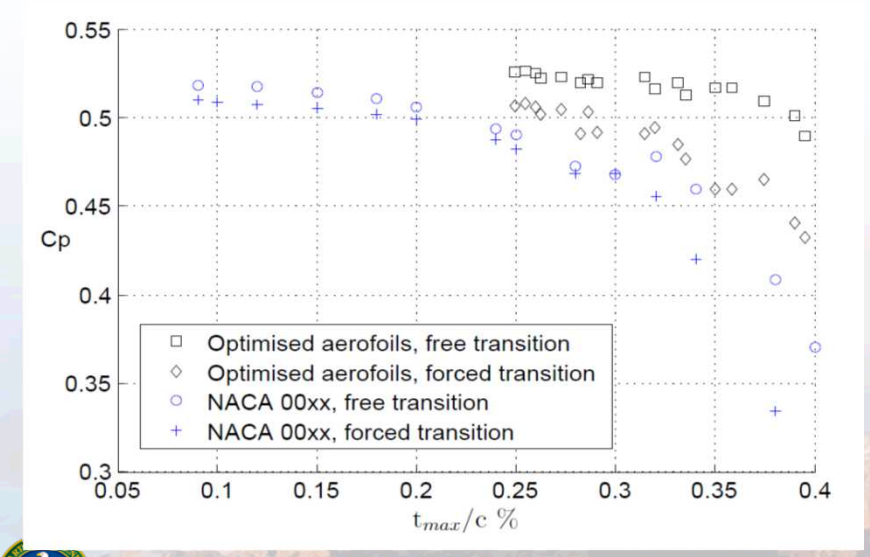
- Blunt Trailing Edge Airfoil CFD (2009)
- Massive WT Loads Databases using Dakota/FAST (2010)
- Office of Science UQ Project (2011-13)
- Offshore Vertical-Axis Wind Turbine FOA Project (2012-14)
- U. of Minnesota/SNL Offshore Wind FOA Project (2012-14)
- SNL/U. of Minnesota SWiFT Modeling (2013-14)

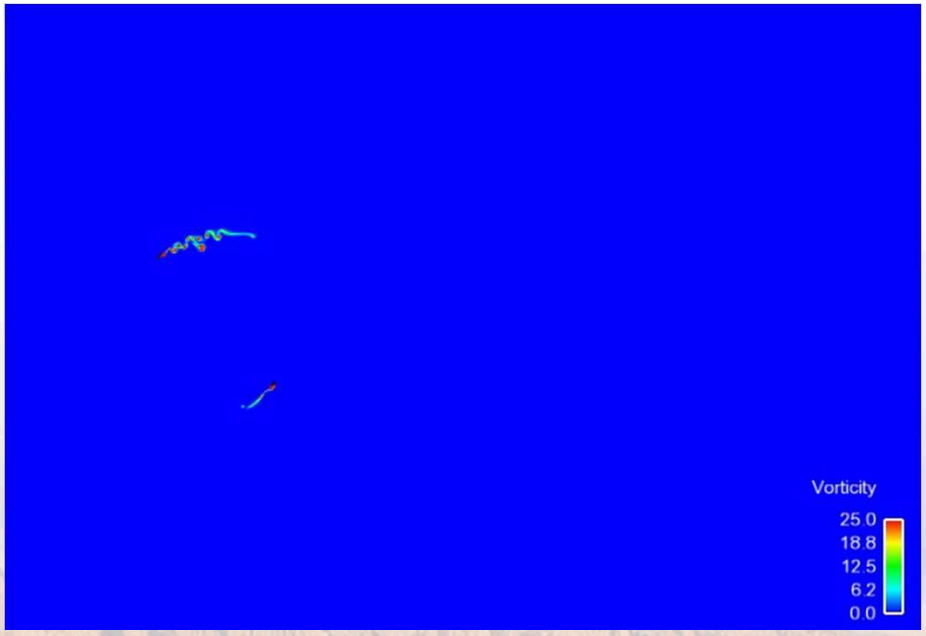


Simulation of VAWT Aerodynamics

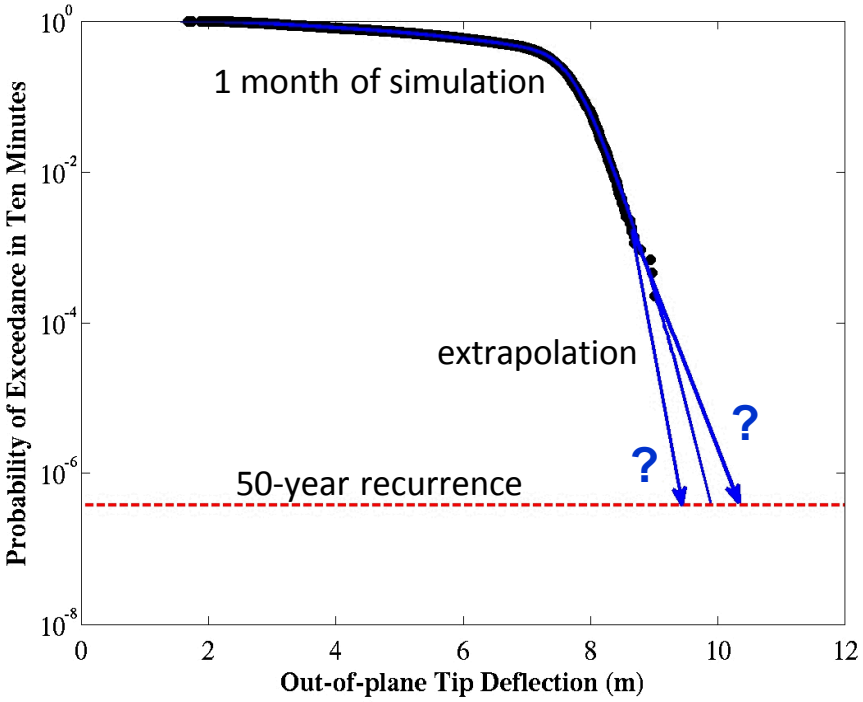
- TU-Delft is designing novel airfoils for large, offshore vertical-axis wind turbines.
- Sliding mesh CFD simulations are being used to define performance under soiled blade conditions.







Wind Turbine Extreme Load Extrapolation



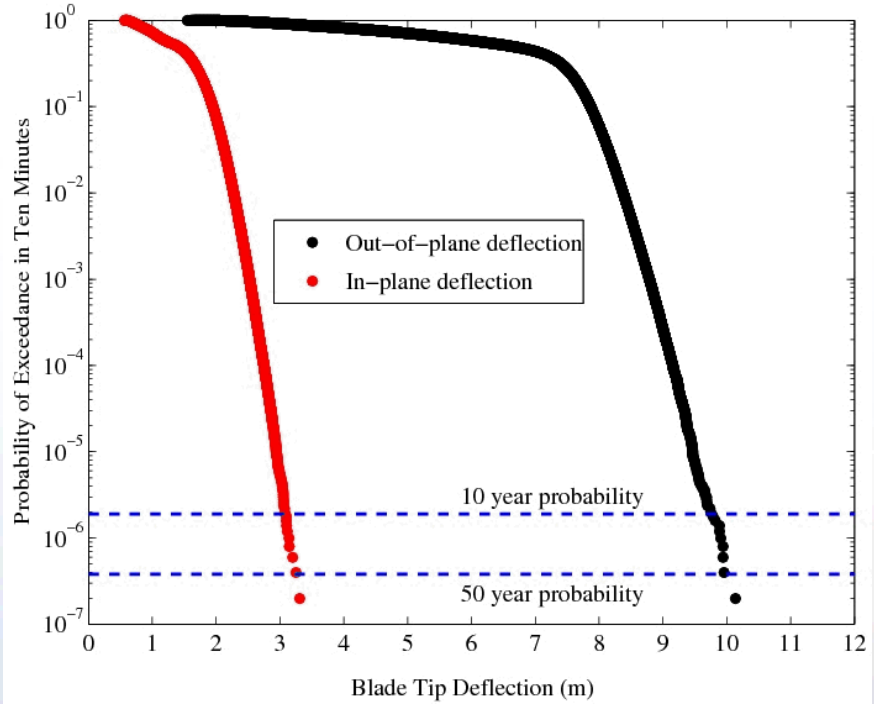
From: IEC 61400-1 Ed. 3 – Wind Turbine Design Standards

For DLC 1.1 the characteristic value of load shall be determined by a statistical load extrapolation and correspond to an exceedance probability, for the largest value in any 10-min period, of less than or equal to 3.8 x 10-7, (i.e. a 50-year recurrence period) for normal design situations.

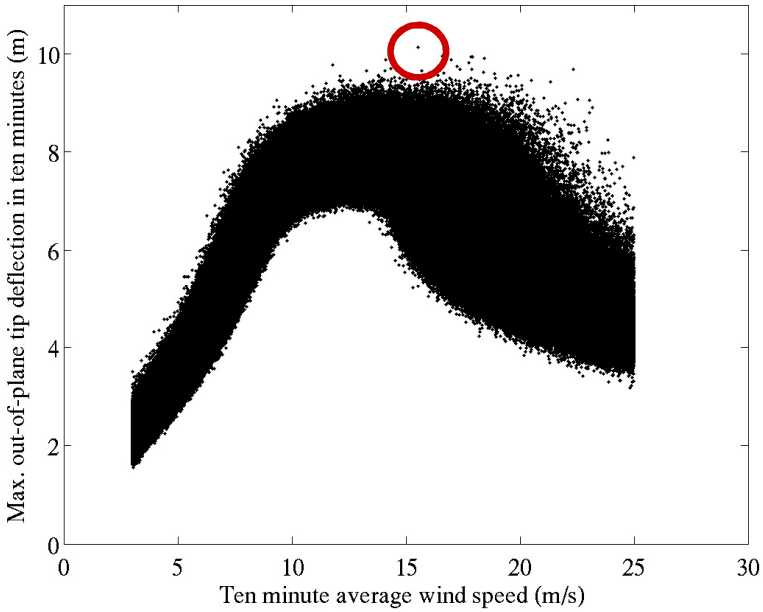
Aero-elastic Load Simulations

- **DAKOTA**
  - Simulation framework developed at SNL
  - Enables large-scale parameter studies, sensitivity analysis, optimization, and UQ
  - dakota.sandia.gov
- **Simulation Procedure**
  - DAKOTA samples two random wind seeds and mean wind speed for each sim using a Latin Hypercube sampling method
  - DAKOTA asynchronously schedules a simulation on each available core
  - TurbSim, FAST, Crunch are run in sequence for each simulation
  - Random seeds, mean wind speed, and 10-minute extreme values are saved by DAKOTA
- **Stats**
  - **5,020,189 simulations performed (~96 years)** in six separate batches
  - 1028 cores used on Red Sky
  - 4.5 days of total wall-clock time

Extreme Tip Deflections



Out-of-Plane



Summary

- **SNL is actively adapting its HPC simulation capability for problems in wind energy.**

- **The potentially differentiating capabilities at SNL are**
  - Expertise and track record on scalable algorithms
  - Expertise and experience with probabilistic analysis using HPC